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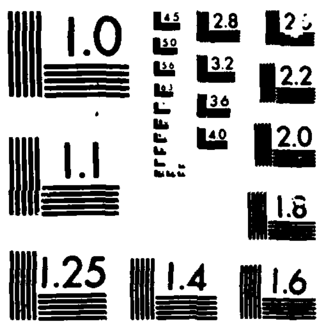

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THE EFFECT OF SPECTRALLY SELECTIVE FILTERS ON VISUAL SEARCH PERFORMANCE

G. T. Chisum, J. B. Sheehy, P. E. Morway
and G. K. Askew
Aircraft and Crew Systems Technology Directorate (Code 60B1)
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974-5000

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The effect of five spectrally selective filters on the performance of an acuity dependent visual search task was evaluated. The filters were: (A) a neutral density filter (control condition); (B) a 5200A green interference filter; C) a 3215-250 red filter; D) a neodymium visor; and (E) a holographic filter. The observers were presented with five blocks of ten slides per filter. Each slide projected a 6 by 6 deg field of 900 ten min of arc letter Os which contained a single Landolt C. The observers were required to search the field and report the orientation of the opening in the C. The opening in the C, which subtended 2.64 min of arc, required an acuity of 0.39 for detection. Response time, error rate, accommodative accuracy, and the number of fixations and their duration were recorded for each slide presentation. The results demonstrate that filter type had no effect on any of the response measures. During the first three trial blocks the observers appeared to optimize their search strategies, after which

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they began to revert to their initial performance levels. Although this effect was not supported statistically, this trend indicates that initially search proficiency increases with practice after which it is offset by fatigue.

Visual searching, Visual acuity, Accomodation, Fixation, Human performance.

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INTRODUCTION

Recent advances in visual displays and eye protection have resulted in an increased exposure of flight crews to spectrally selective environments. The nearly monochromatic stimuli from a heads-up display, the laser stimuli from the holographic head-up displays, or spectrally selective visors provide intermittent monochromatic stimuli of varying duration. These devices necessitate that the user interact with a spectrally distorted world for the duration of the mission while performing a variety of visual tasks both within and outside the cockpit. The tasks, which include reading instruments, identifying controls, switches, weather navigation check points, and detecting and identifying targets could theoretically be affected by the prevailing chromaticity.

Spectral composition could affect performance by altering the normally expected stimulus response relationships. The accommodative system relies on both chromatic aberrations and blur when focusing an object. If accommodative accuracy differed as a function of target wavelength, resolution would degrade as larger accommodative leads (overaccommodation) and lags (under-accommodation) are introduced. Charman and Tucker[1] found that untrained subjects initially made variable accommodative responses, but after adequate practice equally accurate accommodative responses were made regardless of the spectral composition of the stimuli. Acuity did begin to degrade, but only for wavelengths below 405 nm, otherwise there were no differences in acuity or accommodative accuracy.

Monochromatic stimuli could possibly alter patterns of search and fixation. However, it has been demonstrated that pursuit eye movements and fixational quality are not dependent on the color of the target, but rather on the shape, size, luminance and contrast of the target[2,3]. These results again suggest that spectrally selective filters should not affect visual task performance.

In order to evaluate the effect of spectrally selective filters a performance measure which encompasses many of the aircrew's visual tasks is necessary. One possible measure is a visual search task which requires the observer to search a large array of elements and report a critical, resolution dependent aspect of a target. Both accommodative accuracy and proficient search strategies would be required in order to respond rapidly and accurately. Visual search time depends primarily on the number and density of background items[4] and the number of relevant stimulus dimensions[5]. Previous visual search research has enhanced the conspicuity of the targets by using color, texture, and symbology, but none have compared search times using displays which differ only in chromaticity. Simple response time has been shown to be unaffected as long as target brightnesses are equated[6,7], which suggests that visual search times should also be unaffected by the prevailing chromaticity.

The present experiment assesses the effects of spectrally selective environments by requiring observers to search a field of Os to find a single Landolt C and indicate the orientation of the C while wearing one of five spectrally selective filters.

METHOD

OBSERVERS

Seven observers, two female and five males, were chosen from a group of eleven volunteers. A Titmus Vision Tester, a Snellen Eye Chart, the Farnsworth-Munsell 100 Hue Test and the Dvorine Pseudo-Isochromatic Plates were used to insure that the observers had a minimum visual acuity of 20/25 and normal color vision.

APPARATUS

A Stanford Research Institute (SRI) three-dimensional eyetracker was used to measure dynamic refractive power and two dimensional eye movements. A DEC PDP-11/23 computer controlled the calibration and experimental procedure, recorded the output from the eyetracker and the subject's response.

A Spectra Pritchard model 198-A-P1 photometer was used to measure target and adapting field luminances. A Varian 2300 spectrophotometer was employed to assess transmittance of the adapting filters.

The apparatus used for calibration of the eyetracker consisted of targets at specified locations and distances. The accommodation targets were black and white 7.27 cy/deg horizontally oriented squarewave gratings (0.14 ft L). The area of the grating subtended 1.10 degs of arc at distances of 1, 1.5, 5, and 13 m. Seven red light emitting diodes (LED's), each of which subtended 13.75 min of arc, were used to calibrate horizontal eye position. The LED's (mean luminance = 1.58 cd/m) were positioned 2.5, 5, and 10 deg to the left and right of the center LED on an arc located 1 m from the observer. Vertical eye calibration was accomplished using twenty 35 mm slides projected onto a screen 13 m away. Each slide contained one white "C" which subtended 10 min of arc on a black background (mean luminance = 24.19 cd/m). The C could be positioned in any one of 36 locations of a 6 by 6 grid.

An American Optotype Company Projecto-Chart with an Ilex shutter was used to project a 10 min of arc fixation cross onto the screen. Slide presentation and duration was controlled by a Kodak Carousel projector and an Ilex shutter. The target slides were back-projected onto the screen located 13 m from the subject. Each slide (total of 50) contained 900 - 10 min of arc black letters, 899 letter O's and one Landolt C, on a white background (mean luminance = 24.19 cd/m) arranged in a 30 by 30 matrix (6 by 6 deg). The gap in the C subtended 2.64 min of arc which required an acuity of 0.39 for detection. Inter letter spacing at the closest point was 1.85 min of arc.

The five adapting filters used were: 1) A neutral density filter of 3.8% transmittance (Condition A); 2) The 5200A interference filter which simulated the wavelength of the phosphor found in many cockpit displays (Condition B); 3) A 3215-250 filter to simulate the red cockpit lighting (Condition C); 4) A neodymium laser protective visor which rejects 1064 nm wavelengths (Condition D); and 5) A holographic filter which rejects 532 nm wavelengths (Condition E). Figure 1 presents percent transmittance as a function of wavelength for the five adapting filters.

PROCEDURE

Each observer participated in a total of eight one hour sessions. After the initial screening the experimental and calibration procedures were explained to the observer who then indicated consent to participate by signature. Next the observer was fitted with a dental impression bite plate. The entire first session, the first and last part of the experimental sessions, and the entire final session was devoted to calibration of accommodative response and eye movements.

Prior to the start of each session the observer dark adapted for 25 minutes. Two observers, who experienced pupillary contractions with stimulus onset, were administered two drops of 2.5% *Neo-synephrine* in each eye prior to each session. Preliminary trials with and without the

application of the *Neo-synephrine* confirmed that the amplitude of the accommodative response was not measurably reduced by the use of this mild mydriatic.

After the adaptation period the observer's horizontal eye movements were calibrated. At a signal from the experimenter, the observer positioned on the bite board, saccaded to the illuminated LED, fixated the LED for four seconds, and then saccaded to the next LED as it was illuminated. The sequence started at the center LED (0 degs) and proceeded 2.5, 5, and 10 degs to the left, and then reversed sequence and returned to the center. Rightward movements were then calibrated using the same LED progression (i.e., 2.5, 5, and 10 degs to the right and then back to center). Six full swings encompassing all seven LEDs were completed before continuing.

After a short rest period, the observer continued with the vertical eye movement calibration procedure. Figure 2 presents the grid used for calibration. The observer was instructed to look at the white letter "C" on a black background and saccade to each new position as it appeared. Beginning in the center position, the "C" moved diagonally to the lower right position (#1) and then sequentially across to the left most position (#7). The C then moved diagonally up to position 8 and began the sequential progression across to position 15. This progression continued until 20 eye positions had been recorded. The C remained in each position for four sec.

The four accommodation targets (1, 1.5, 5, and 13 m) were presented one at a time for four seconds each beginning with the 1 m target, progressing to the 13 m target and then returning to the 1 m target. This sequence was repeated seven times with a one minute rest period between runs.

The next six experimental sessions, the first of which was considered practice, were devoted to data collection. The observer was informed that when the buzzer sounded to position on the bite board and fixate the red cross located in the center of the screen. Once the experimenter was satisfied that the eyetracker was operating properly a target slide was presented. The observer was instructed to rapidly search the background of O's to find the C and using the four key response pad indicate the position of the break in the C. If there was not a response within 55 sec the instruction was to guess the C's orientation.

The next six experimental sessions, the first of which was considered practice, were devoted to data collection. The observer was informed that when the buzzer sounded to position themself on the bite board and fixate the red cross located in the center of the screen. Once the experimenter was satisfied that the eyetracker was operating properly a target slide was presented. The observer was instructed to rapidly search the background of O's to find the C and using the four key response pad indicate the position of the break in the C. If there was not a response within 55 sec the instruction was to guess the C's orientation.

The observer performed 50 trials of the search task using one filter in any given session. In order to equate the percentage of light transmittance among filters a neutral density filter of 43.3% transmittance was placed over the projector lens for conditions B, C, D, and E. The resulting average transmittance for all filters was 3.8%. Filter order was counterbalanced among observers.

The final session consisted of a complete recalibration and debriefing. All questions were answered at this time.

RESULTS

The data from two observers were eliminated prior to analysis because of excessive error rates (>60%). Figure 3 presents response time as a function of trial block for the five filters. Average response time was undifferentiated by filter type. Although response time appeared to reach a minimum during the third trial block, a two factor ANOVA (filter type by trial block) failed to reveal any significant main effects or interaction ($p>.20$).

Error rate as a function of trial block for the five filters is presented in figure 4. Subjects committed on the average 2.5 errors per experimental session (50 trials) regardless of filter type. Average error rate reached a minimum during the third trial block after which it began to increase. A two factor ANOVA failed to reveal a significant main effect of filter type or trial block ($p>.20$). The interaction between filters and trial blocks also failed to reach to significance ($p>.20$).

Accommodative accuracy as a function of filter type is presented in figure 5. On the average subjects had an accommodative lead (overaccommodation) of 0.43 diopters, however, as shown in figure 5, there was a large amount of variability across trial blocks for all filters. A two factor ANOVA failed to reveal any significant main effects or interaction ($p>.20$).

The average number of fixations as a function of trial block for the five filters are shown in figure 6. Subjects made approximately 15% more fixations with the neutral density and red filter than with the green, neodymium, and holographic filters. There also appears to be a practice effect with the minimum number of fixations occurring during the third trial block. This reduction suggests that the subjects became progressively more efficient in their search strategies during blocks one, two and three, after which they started to fatigue. However, both of these trends and their interaction failed to reach significance ($p>.20$).

Fixation duration as a function of trial block for the five filters is presented in figure 7. As would be expected the number and duration of fixations are inversely related, that is, there are fewer fixations in blocks of trials where fixations were correspondingly longer. A two factor ANOVA failed to demonstrate a significant main effect of filter type, trial block or their interaction ($p>.20$).

DISCUSSION

The results indicate that skilled visual performance is unaffected by prevailing chromaticity. There was evidence of a progressive improvement in search strategy for all response measures reaching a minimum in the third trial block, however, all main effects of trial blocks failed to reach significance. As found previously[1,8], average accommodative accuracy was unaffected by the nearly monochromatic filters of the present study. Also, similar to previous research, the elimination of chromatic aberration as an accommodative cue did result in considerably more variability than was observed during calibration runs without the filters.

The differences observed in the number and duration of fixations as a function of trial block were accompanied by a corresponding decrease in response time. It appears that the variations might be indicative of a fine tuning of the observers' search strategies in order to optimize the speed and accuracy of the response. After some time on task the observers learn to make fewer fixations of longer duration in order to decrease response time. However, as the observers begin to fatigue they revert to previous patterns of fixation associated with longer response times.

In the present study transmittance of the different filters was carefully controlled to insure the same average luminance for all filters. As shown previously[6,7], response time was unaffected as long as the brightness of the targets was equated. This suggests that in addition to the obvious need for high quality optics the critical design parameter for effective eye protection is the overall transmittance in the visible portion of the spectrum.

The observed changes associated with increasing trial block reinforces the need to further explore the effects of practice and fatigue, and the interaction of fatigue with practice and task difficulty. It is well known that fatigue related performance decrements can be temporarily offset by compromising another aspect of task performance such as a speed accuracy tradeoff. Also the user should be exposed to the different filters in order to facilitate effective user strategies. Search strategies will vary from user to user, however, exposure to representative visual tasks while wearing spectrally selective devices will enhance the fine tuning of search strategies.

ACKNOWLEDGEMENTS

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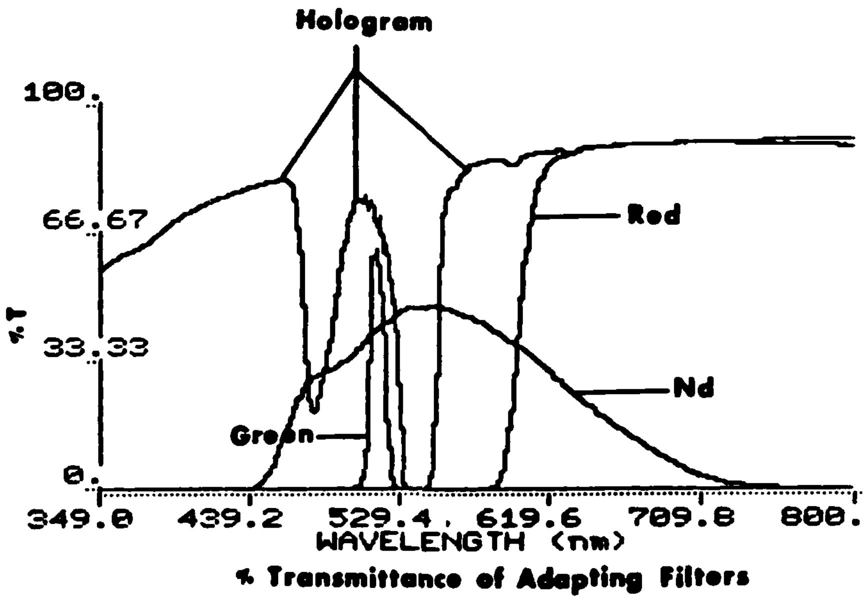

Figure 1. Percent Transmittance As A Function Of Wavelength For The Five Filters.

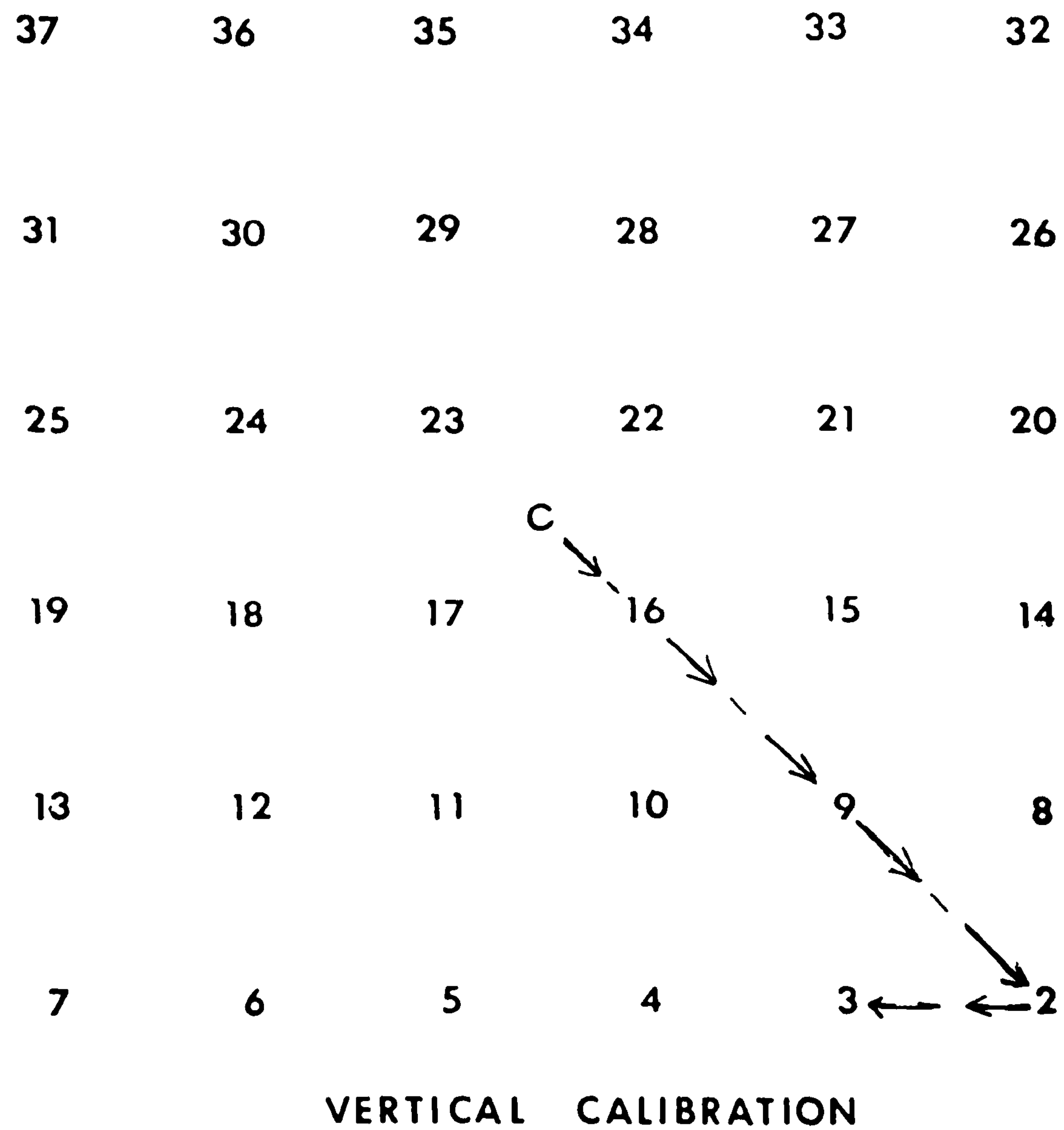

Figure 2. The Grid Depicting The Locations Of The C's Used To Calibrate Vertical Eye Movements.

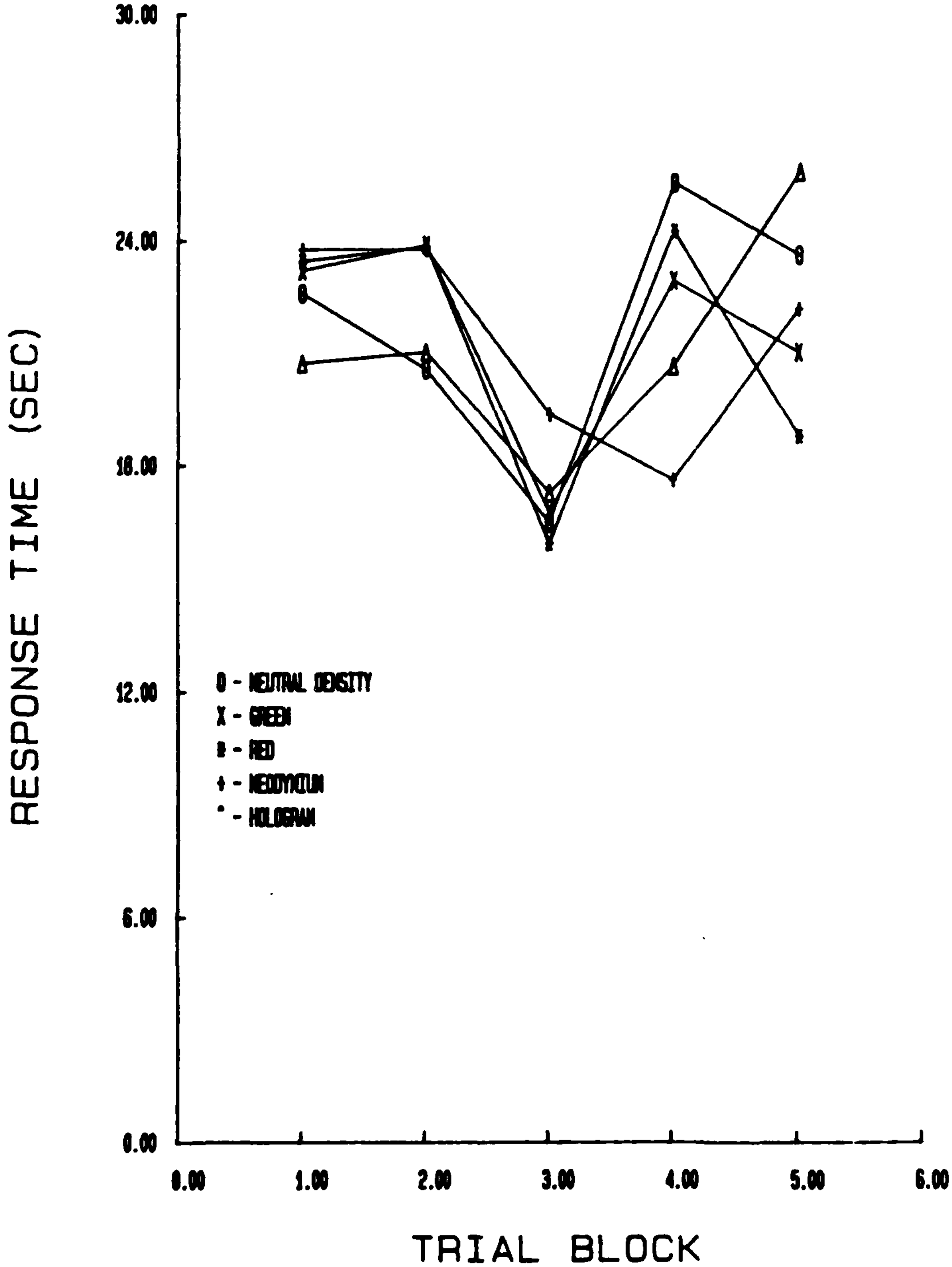

Figure 3. Average Response Time As A Function Of Trial Block For The Five Filters.

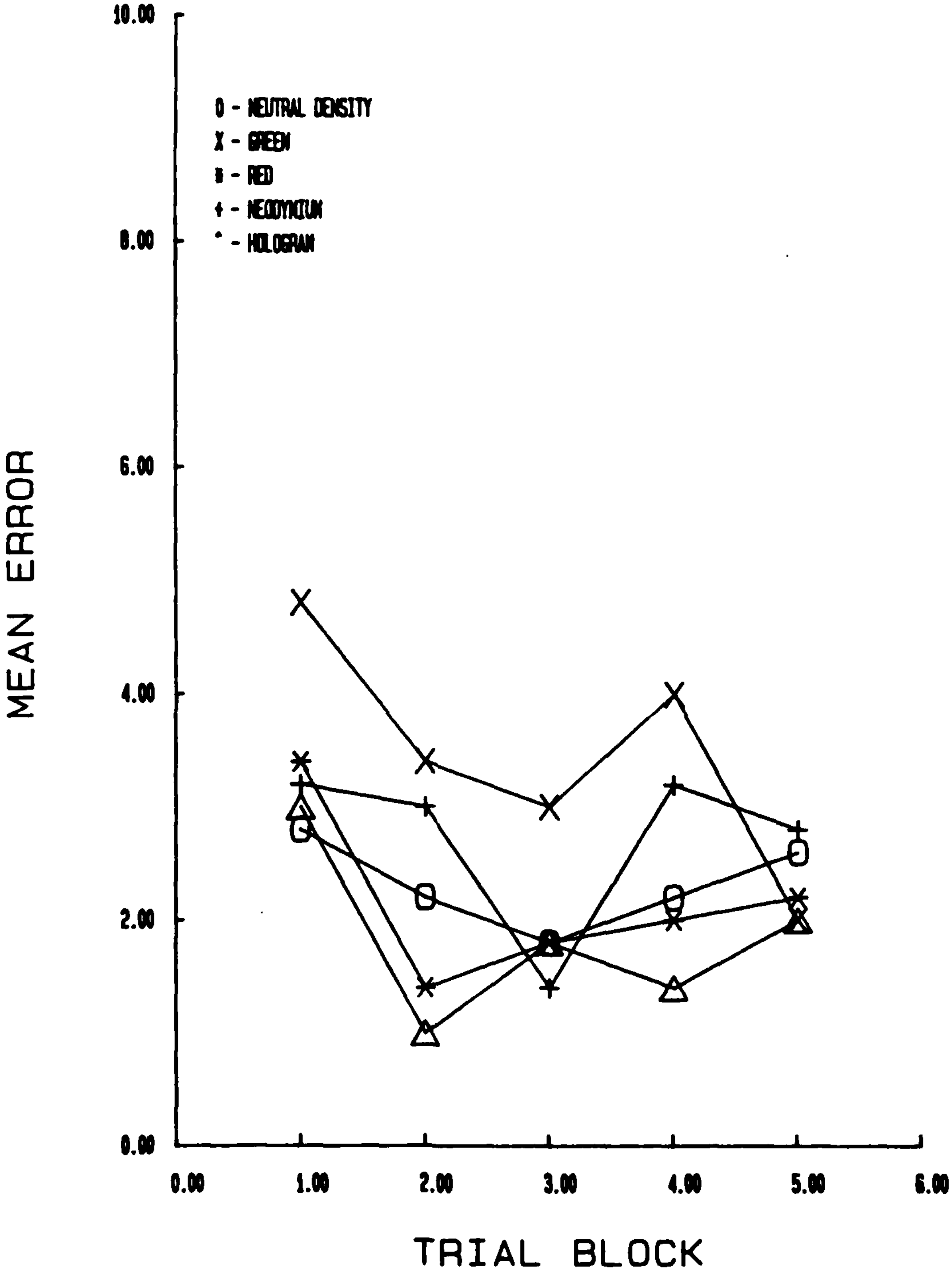

Figure 4. Average Error Rate As A Function Of Trial Block For The Five Filters.

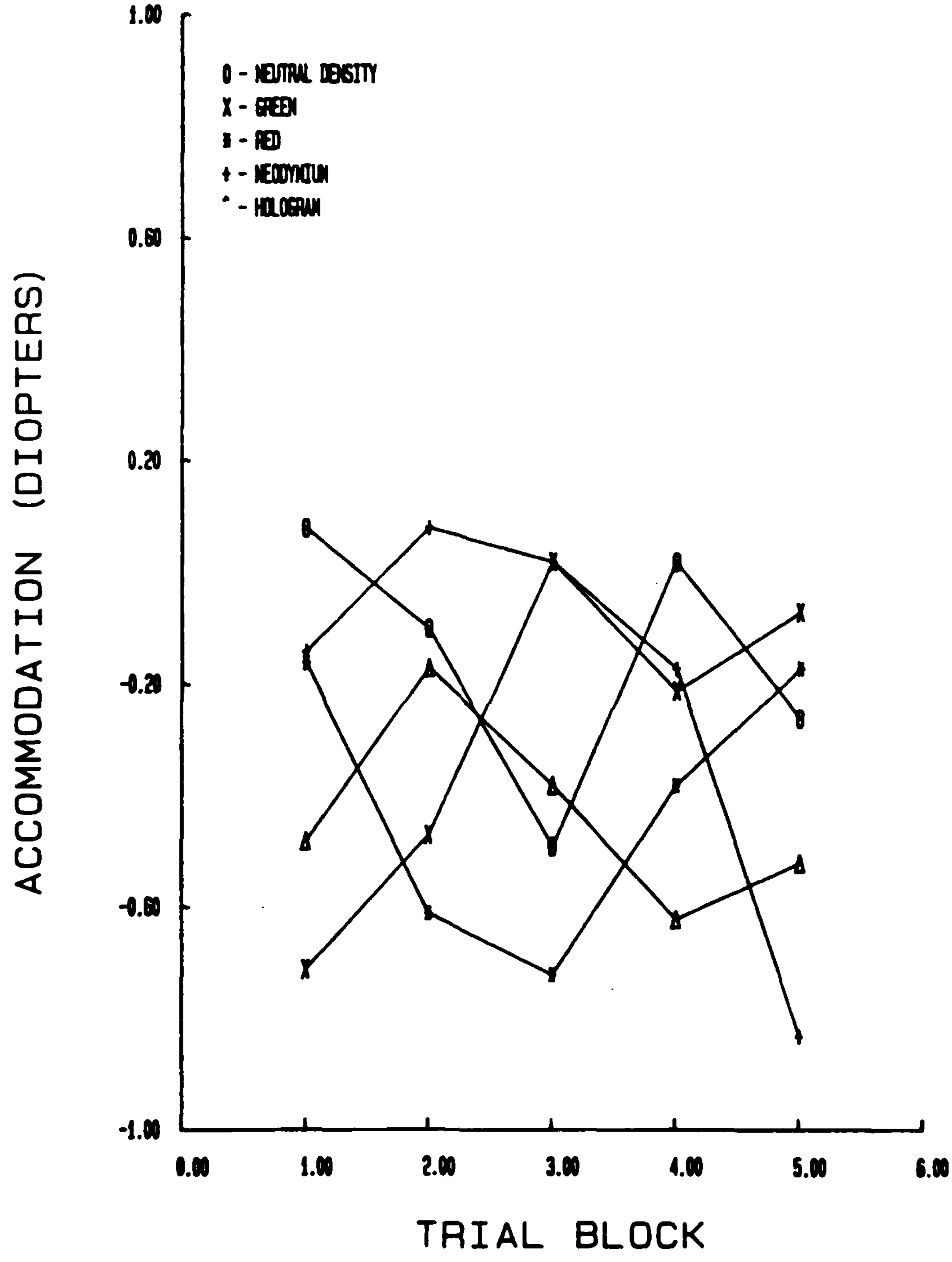

Figure 5. Mean Accommodative Accuracy As A Function Of Trial Block For The Five Filters.

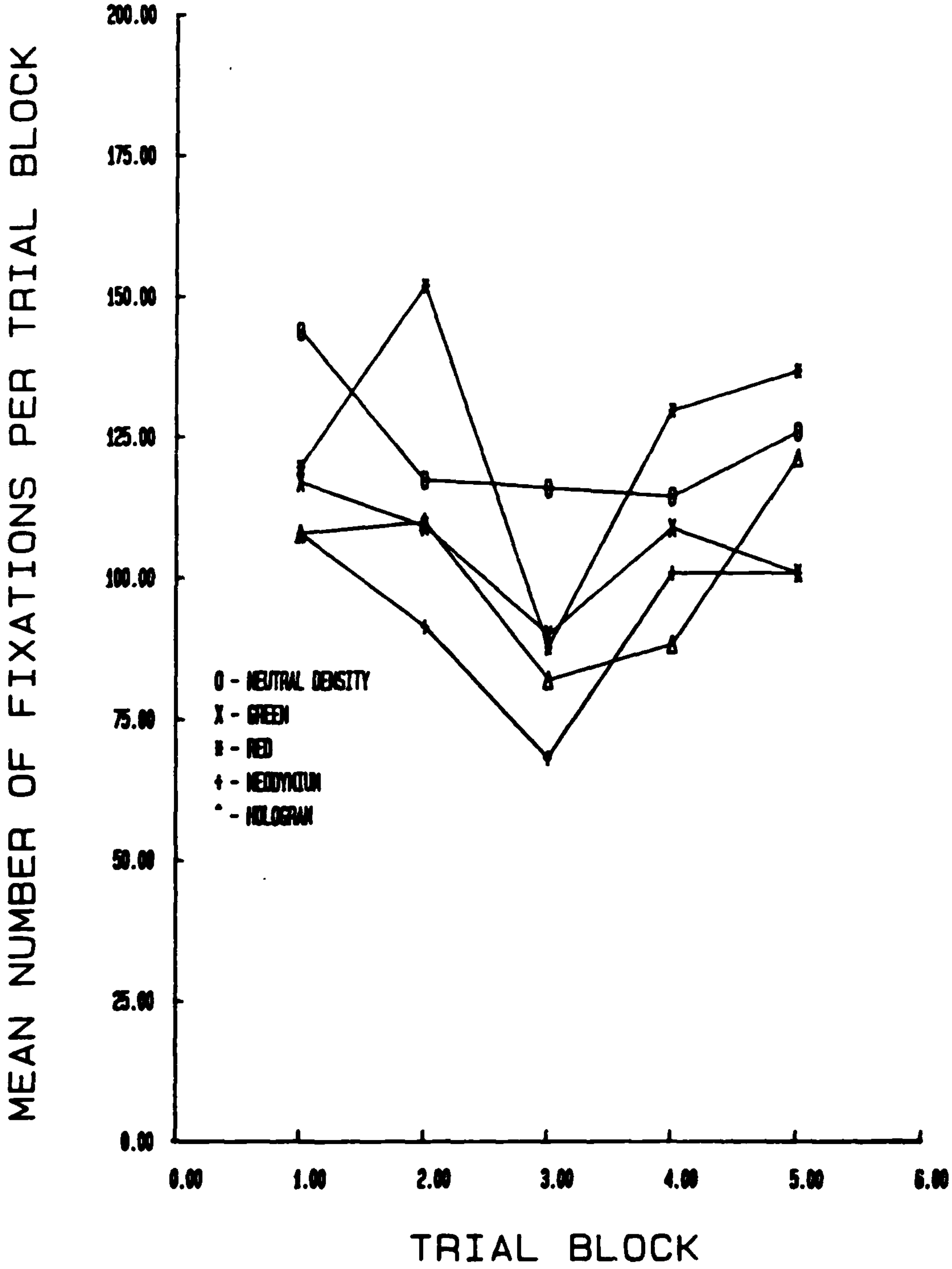

Figure 6. The Average Number Of Fixations As A Function Of Trial Block For The Five Filters.

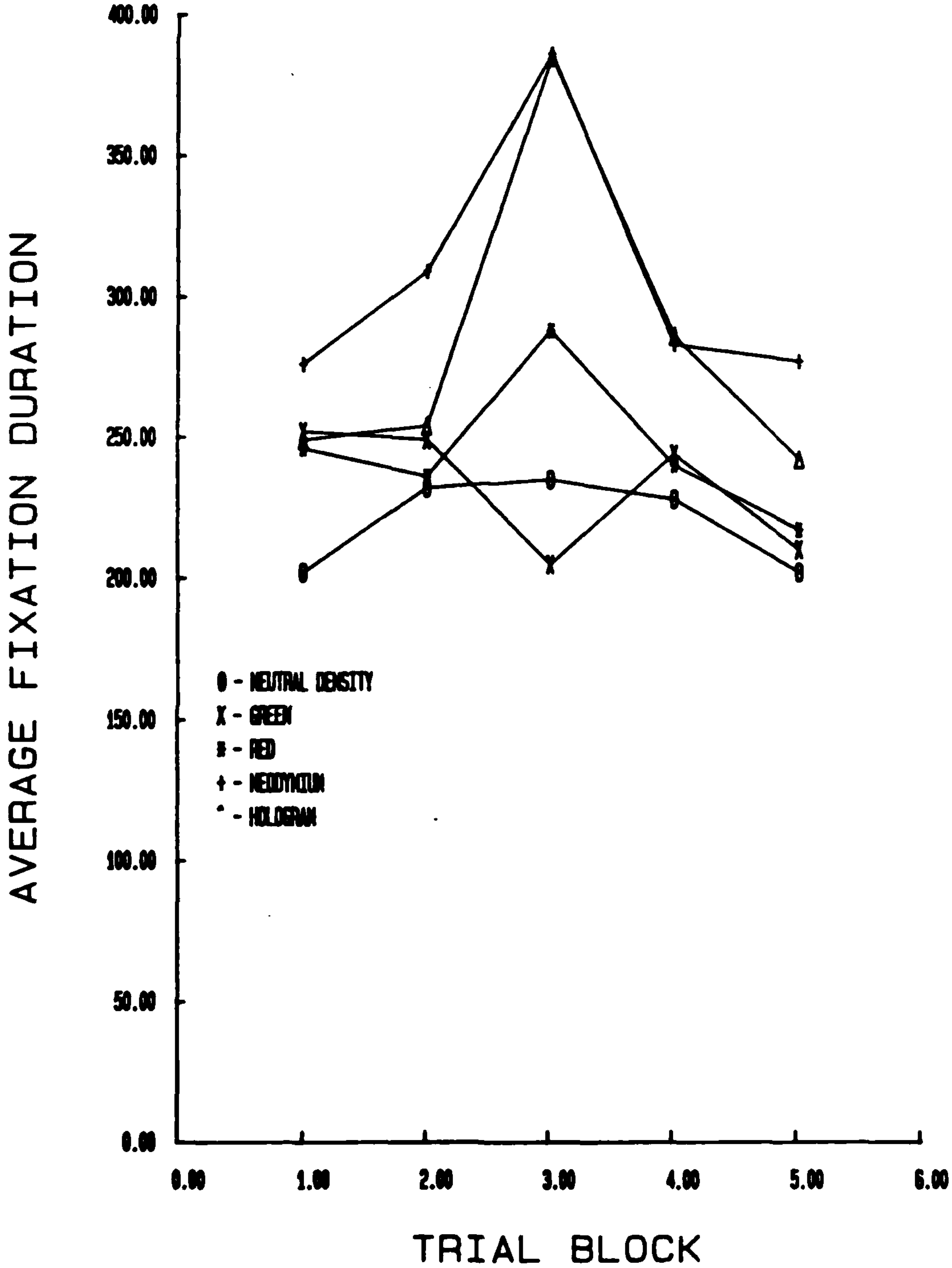

Figure 7. Average Fixation Duration As A Function Of Trial Block For The Five Filters.

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